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COMPARISON OF VARIOUS FILTERING TECHNIQUES USED FOR REMOVING HIGH FREQUENCY NOISE IN ECG SIGNAL

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Abstract— About 8.8 million males and 6.6 million females alive today have been affected by Coronary Heart Disease (CHD). Of these 5.0 million males and 2.6 million females have been diagnosed with Myocardial Infarction (MI), according to the statistics updated by the American Heart Association (AHA) in 2013 [1]. Early diagnosis and appropriate treatment of CHD is essential to minify the mortality rate due to CHD. This accentuates the need for an accurate and reliable equipment for monitoring the health conditions of hearts of human beings to treat the disease in advance before it brings about an irrevocable change in their body. One of the equipment's used for this purpose is an Electrocardiograph, and the acquired signal is called an ECG signal. The acquisition process of this signal is hindered by a number of artifacts and removal of these artifacts is of paramount importance before the ECG signal could be used for disease diagnosis purpose.Keywords—Phishing, Vishing, SMSishing, Social Engineering, ZeKo

I. INTRODUCTION

Electrocardiography is a transthoracic interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the surface of the skin and recorded by a device external to the body [2]. ECG signals are composed of P wave, QRS complex and T wave. The waveform is used to measure the rate and regularity of heartbeats, as well as the size and position of the chambers, the presence of any damage to the heart, and the effects of drugs or devices used to regulate the heart, such as a pacemaker.

The most prevalent artifacts present in the ECG signal can be divided into 1.Low frequency artifacts 2.High frequency artifacts and 3.Physiological Interferences. These artifacts must be removed prior to abnormality detection from the waveforms, else there would be misinformation about the diseases.

Our primary focus is on removing the high frequency noise in the ECG signal. The common high frequency noises are the Instrumentation noise and Electrode contact noise. Raghu has proposed a method of denoising ECG signal using Daubechies wavelet [3]. MA Mneimneh et al proposed a method by using a non-linear least squares optimization technique [4].

Our choice of filters for removing the aforementioned noises are Digital Filters. Analog filters can also be used, but non-linear phase shift is introduced by the implementation of the same. [5]

The performance of the various filters are compared in removing the high frequency noises and the results are tabulated below.

II. PROPOSED SOLUTION

An ideal IIR filter is designed and then the infinite impulse response is truncated by multiplying it with a finite length window function. The result is a finite impulse response filter whose frequency response is modified from that of the IIR filter. Multiplying the infinite impulse by the window function in the time domain results in the frequency response of the IIR being convolved with the frequency response of the window function. [6]

$$h[n]=w[n].\ hd[n]$$

The transfer function of designed filter will be found by transforming impulse response via Fourier Transform

$$H(e^{-jw}) = \sum_{n=0}^{N} h[n].\, e^{-jnw}$$

If the transition region of designed filter is wider than needed, it is necessary to increase the filter order, re-estimate the window function coefficients and ideal filter frequency samples, multiply them in order to obtain the frequency response of designed filter and re-estimate the transfer function as well. If the transition region is narrower than needed, the filter order can be decreased for the purpose of optimizing hardware and/or software resources. The various window functions are discussed below: [7]

A. *Triangular (Bartlett) window*

The triangular (Bartlett) window is one among many functions that lessens the effects of final samples. Due to it, the stopband attenuation of this window is higher than that of the rectangular window, whereas the selectivity is less. Filters designed using this window have wider transition region than those designed using the rectangular window. Therefore a higher order filter is needed. Higher attenuation is obtained at the cost of increased components and higher order. Computation of coefficients is very easy. The triangular window coefficients can be expressed as

$$w[n] = \begin{cases} \frac{2n}{N-1}; 0 \leq n \leq \frac{N-1}{2} \\ 2 - \frac{2n}{N-1}; \frac{N+1}{2} \leq n \leq N-1 \end{cases}$$

B. Hanning Window

The Hanning window is used to lessen bad effects on frequency characteristic produced by the final samples of a signal being filtered. Digital filters designed with this window have higher stopband attenuation than those designed with triangle function. The transition region is the same as for triangular window, which makes this function one of the most desirable for designing.

Another advantage of this window is the ability to relatively quick increase in the stopband attenuation of the following lobes. The Hanning window belongs to a class of generalized cosine windows .The Hanning window coefficients can be expressed as:

$$w[n] = \frac{1}{2}\left[1 - \cos\left(\frac{2\pi n}{N-1}\right)\right]; 0 \leq n \leq N-1$$

C. Kaiser Window or Kaiser-Bessel window

The minimum stopband attenuation depends on the specified window, whereas an increase in filter order affects the transition region. The windows described before are not optimal. An optimal window is a function that has maximum attenuation according to the given width of the main lobe. The optimal window is also known as Kaiser window. Its coefficients are expressed as [8]

$$w(n) = \begin{cases} \frac{I_o\left(\pi\alpha\sqrt{1-\left(\frac{2n}{N-1}-1\right)^2}\right)}{I_o(\pi\alpha)}, & 0 \leq n \leq N-1 \\ 0 & otherwise, \end{cases}$$

where N is the length of the sequence, I0 is the zeroth order Modified Bessel function of the first kind, α is an arbitrary, non-negative real number that determines the shape of the window.

D. Hamming Window

The Hamming window is one of the most popular and most commonly used windows. A filter designed with the Hamming window has minimum stopband attenuation of 53dB, which is sufficient for most implementations of digital filters. The transition region is somewhat wider than that of the Hanning window, whereas the stopband attenuation is considerably higher. The transition region can be changed by changing the filter order. The transition region narrows, whereas the minimum stopband attenuation remains unchanged as the filter order increases. The Hamming window coefficients are expressed as:

$$w[n] = 0.5 - 0.46\left[1 - \cos\left(\frac{2\pi n}{N-1}\right)\right]; 0 \leq n \leq N-1$$

The Hamming window belongs to a class of generalized cosine functions

III. IMPLEMENTATION

The ECG waveform has been taken from the www.physionet.org database. The data consists of many cycles of ECG corrupted by high frequency noise. The implementation of various filters was done using MATLAB R2009b version. Both the types of filters, i.e., FIR and IIR, were designed for cut-off frequency (f_c) of 60 Hz and sampling frequency (f_s) was chosen as 800 Hz for FIR filters and 2000 HZ for IIR filters which was chosen based on the sampling theorem. The algorithm implemented for this paper was:

- Extract a single cycle of ECG from the given data.
- Set cut-off frequency and the sampling frequency.

$$f_s > 2\,(f_c)$$

- Define the filter function using the various commands inbuilt in MATLAB.
- Apply the filter on to the ECG signal.
- Calculate the SNR value of the signal

SNR (dB) = 10 log (signal power)/(noise power)

- View the ECG waveform

IV. RESULTS AND DISCUSSION

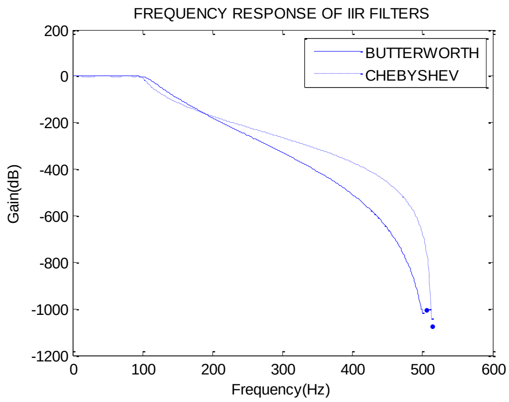
After the implementation of the filters, it was found that the FIR filters gave better results than the IIR filters. The performance of the various filters with respect to the SNR values obtained has been tabulated.

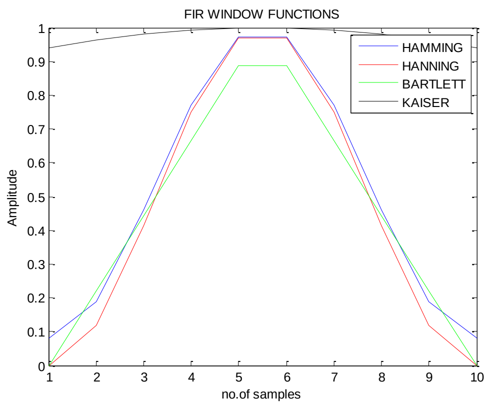
TABLE 1 – TABLE SHOWING DIFFERENT SNR VALUES OF THE ECG SIGNAL AFTER IMPLEMENTATION OF THE FILTERS

FILTER TYPE	ORDER	AVERAGE SIGNAL POWER (dB)	NOISE POWER(dB)	SNR (dB)
Chebyshev	7	-22.3961	-54.9677	32.6144
Butterworth	12	-22.3961	-49.7623	27.3233
Hamming	10	-22.3773	-75.544	53.1697
Hanning	10	-22.3773	-75.4026	53.024
Bartlett	10	-22.3773	-75.5158	53.1373
Kaiser	10	-22.3773	-76.2669	**53.8885**

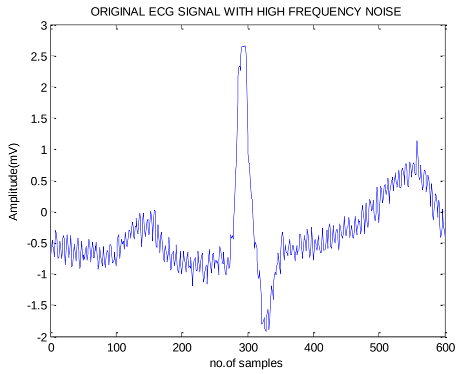
In the IIR filters, the performance of Chebyshev Type I filter outweighed the performance of Butterworth filters by providing the same cut-off frequency value at a lower order of 7 as compared to the Butterworth filter with an order of 12. Among the FIR filters, the Kaiser window function showed the best performance as it showed a good SNR of 53.8885. The FIR filters worked by maintaining the signal power constant and only tried to decrease the noise power and the filter order was also maintained at 10 for all window functions applied. It has also been observed that high frequency noise has been reduced without losing the signal information.

The frequency response of the IIR filters and the various windows used are shown in the figure.

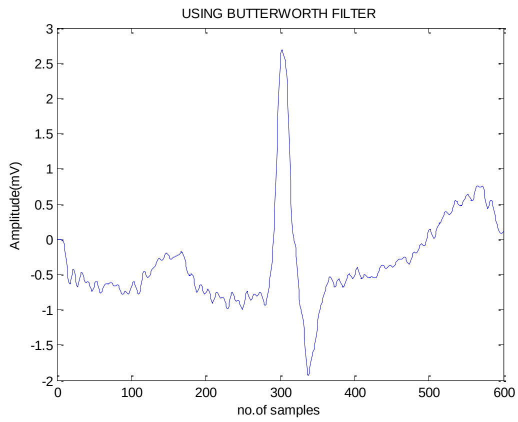


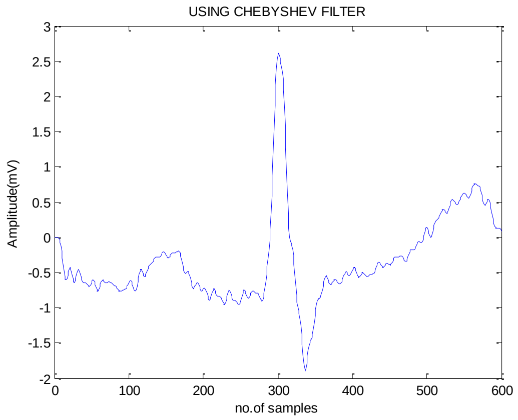


The original ECG signal corrupted by high frequency noise is given below in Figure 2:

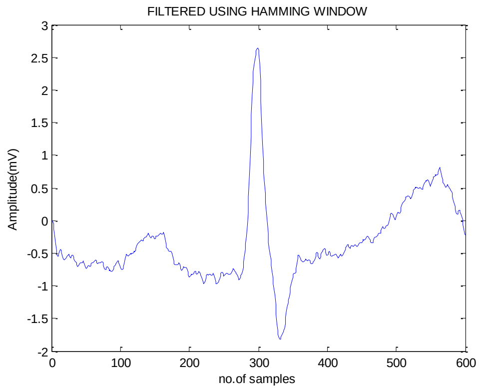


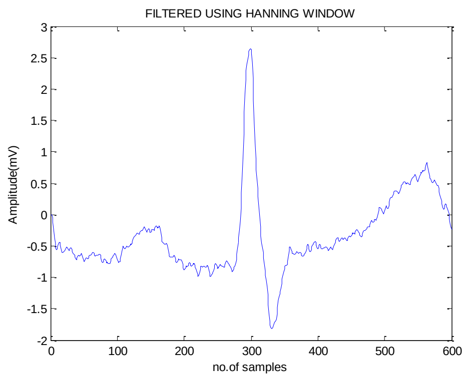
The reponse of IIR filters on ECG signal is given below.

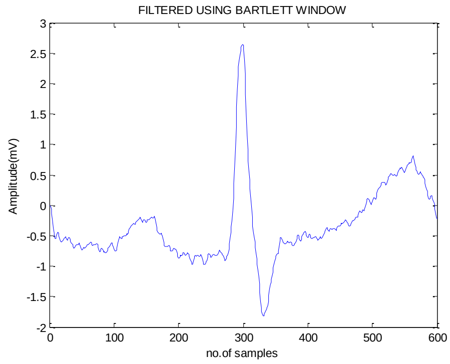




The ECG signal after filtering using FIR filters is given below







V. CONCLUSION

Thus the various filters and their performance was studied in this paper and the most suitable filter for removal of high frequency noise was studied. The FIR filters are better than the IIR filters for the following reasons: (i) high stability, (ii) less storage due to less number of coefficients, (iii) no feedback involved. The future scope of this paper is to automate the selection of cut-off frequency instead of doing it as a trial and error method.

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